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ABSTRACT

Three ways in which the term "inquiry" is used are discussed: inquiry as a teaching method, inquiry as a mode of learning and inquiry as a logical disciplinary process. The role of guiding principles of inquiry is analyzed, using a discussion of Harvey's work on the heart to illustrate an inquiry guided by the idea of structure-function. It is argued that guiding principles of inquiry influence problems, facts, hypotheses, interpretations and outcomes. A discussion method is described aimed at teaching an understanding of inquiry as logic. Materials which can be used for "inquiry into inquiry" are listed. (EB)

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ENQUIRY MATERIALS IN SCIENCE TEACHING[1]

This is the first paper in a three part series on enquiry materials in science teaching. Part I is a brief and crucial part for understanding the remaining two parts. In Part I I point out that different people use the word "enquiry" in different ways and that this leads to unnecessary confusion. The various uses are then sorted into three sets of meanings, two of which are treated in the remaining two parts of the paper.

Part II, Enquiry as Logic, is the longest part and describes six general characteristics of enquiry -conceptions governing enquiry, fact, problem, hypothesis, interpretation, outcome. The conceptions (ideas or principles) brought to an enquiry determine the pattern of enquiry from beginning to end. What will and will not pass for fact, the form of the problem and the form of the hypothesis, the direction of the interpretation and the form of the outcomes are all determined by the initial overriding conception. Because of this eminent role of governing conceptions a large portion of Part II is given to an extended illustration of the role of these conceptions in enquiry.

Part III, Enquiry into Enquiry, describes a discussion method for a teaching-learning situation aimed at an understanding of enquiry as logic. The discussion involves the students in an inquiry. The teacher has in mind a set of conditions or structure which a profitable discussion will fulfill and be guided by. These conditions are derived, in part, from enquiry as logic. Students are required to search for evidence to support

1 Presented at the Conference of the Science Teaching Association of Ontario, Toronto, Ontario, 14 November 1969.

positions taken, to compare and contrast the various arguements i.e. the movement from data to positions taken via a process of interpretation, and to engage in the reformulation of arguements. In brief, the class acts as an enquiry community.

Part III further describes various kinds of materials which can serve as the material basis for an enquiry into enquiry discussion.

PART I: CONCEPTIONS OF ENQUIRY

Introduction

This talk grows out of a workshop I conducted at The Ontario Institute for Studies in Education in the summer of 1968 on the development of enquiry materials in science. Some of the people on the panel with me were participants at that workshop. They have developed materials and have used them in their classrooms. Let me introduce each of these people to you.

Wendell Palmer,	Biology Teacher at Westlane Secondary School, Niagara Falls. Mr. Palmer has developed some excellent orginal paper materials on communication in bees.
Harold Bricks,	Science Teacher at Eastern Commerce High School of Science, Toronto. Mr. Bricks, along with John Harvey, Biology teacher at Woodstock, developed the original Watson and Crick DNA paper for classroom use.
John Eix,	Lecturer at OCE. Mr. Eix has developed one of Ernest Rutherford's papers for classroom use and for use with teachers in training.
John Clipsham,	Formerly Ontario teacher and now a doctoral student, OISE. Mr. Clipsham will comment on materials developed by Sister Annette, Science Head, at Nicholson Catholic College, Belleville.

Oscar Chappel, Science teacher at Lively High School, Lively. Mr. Chappell has developed a scientific enquiry game.

While I am introducing people I must thank Keith Telfer who gave me a great deal of help especially on my original plan for this workshop, namely to have video tapes of classroom sessions engaged in enquiry into enquiry.

The format for this afternoon is divided into three parts:

1. A presentation by myself which will set forth selected elements in enquiry appropriate to enquiry curriculum materials and enquiry teaching.
2. Brief tape clips of classroom sessions chosen to illustrate some of the elements in my presentation. The various panel members will describe these clips.
3. Review of enquiry materials at the four tables situated around the room. Each of the people on the panel will be at one of these tables and will talk with you about the materials found there. We are doing this in place of the normal question period.

Conceptions of Enquiry

The word "enquiry" means different things to different people. For some "enquiry" means a method of instruction. The method is seen by some as the only way a child can "really" learn while for others it is seem merely as unstructured play. For others, enquiry means "thinking" or "critical thinking" or "divergent thinking". For still others, enquiry means the logical processes used for inventing, discovering and verifying disciplined knowledge. (By disciplined knowledge I simply mean knowledge developed as part of an ongoing research process and which becomes increasingly powerful in explaining the world.)

This diversity of meanings had led to considerable confusion and ambiguity on the part of school people. Enquiry is a catchy term and has given rise to slogans and bandwaggons. We do not, however, want to give the term one and only one clear definition and thereby throw away the richness in the many meanings. Rather, we need to classify the various meanings and then be clear in our minds, in our conversation, and in our curriculum development activities which of the classes of meaning we are using. Let me suggest a classification which will retain the diversity of meaning and which will let us know what our session to-day is about and what it is not about.

There are, I suggest, three sets of meanings associated with the term enquiry. First, "enquiry" may mean a method of teaching. We talk about "the enquiry method." For many people the enquiry method is unstructured.[1] Students are given the freedom to explore whatever is of interest to them. According to this view, the teacher's role, when requested by the student, is that of guide and source of information and direction. The enquiry method may, however, be highly structured as, for example, in the work of Bruner.[2] According to this view the teacher and the curriculum hide certain specific concepts from the child. The teacher, through the use of appropriate materials and encouragement aids the child in "discovering" the hidden concept.

Second, "enquiry" may mean a mode of learning. This is a psychological

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1 This is a common way of interpreting the use of the term "enquiry" in Living and Learning.

2 See, for example, Jerome S. Bruner, Jacqueline J. Goodnow, and George A. Austin, A Study of Thinking (New York: Science Editions, Inc. 1962.).

set of meanings. Here, the concern is for what the child is doing as he undertakes an investigation. A common view sees the child as a problem solver and stresses hypothesis formation, construction of apparatus and the acquisition of data to solve the problem. Another view is seen in Bruner's psychological conception of the child as a classifier.[1] Here the child learns by construction classes, which, for Bruner, are concepts and relationships among concepts. Still another view is seen in Schwab[2] and Connelly's[3,4] conception of the child as learning by developing habits of thought characteristic of the subject field under study.

Third, "enquiry" may mean the logical processes used in the development and verification of knowledge. Here we talk about the methods of the various sciences and of science generally. The source of understanding for the set of meanings is neither classroom instruction nor people learning. Rather the sources are the literature of the disciplines themselves and the philosophical literature about the disciplines.

We have, now, three sets of ways we can use the term enquiry - enquiry as teaching method, enquiry as mode of learning and enquiry as logical disiplinary process. Our focus today is on the first and third of these, i.e. on enquiry as teaching method and enquiry as logical disciplinary

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1 Ibid.

2 Joseph J. Schwab, College Curriculum and Student Protest (Chicago: University of Chicago Press, 1969).

3 F. Michael Connelly, "Conceptual Structures in Ecology with Special Reference to an Enquiry Curriculum in Ecology" (unpublished Doctoral dissertation, Department of Education, University of Chicago, 1968).

4 F. Michael Connelly, "Conceptual Disciplinary Structures and the Curriculum (paper presented to Division B (Curriculum) of the American Educational Research Association, Los Angeles, 1969).

process. We shall use a term developed by Schwab and call this combined focus "enquiry into enquiry."[1] Thus, we shall talk about logical processes of scientific enquiry on the one hand, and, on the other hand, about a possible method aimed at the teaching of those logical processes. Let us turn to the logical set of meanings of enquiry.

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1 Joseph J. Schwab, "The Teaching of Science as Enquiry," Joseph J. Schwab and Paul F. Brandwein, The Teaching of Science (Cambridge, Mass.: Harvard University Press, 1962).

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This is the second paper in a three part series on enquiry materials in science teaching. Part I, Conceptions of Enquiry, pointed out that different people use the word "enquiry" in different ways and that this leads to unnecessary confusion. In order to preserve the richness of meaning in the many uses of "enquiry" a classification of three sets of meanings was presented - enquiry as teaching method, enquiry as mode of learning, enquiry as logical disciplinary process. Parts II and III respectively treat enquiry as logic and enquiry as teaching method.

PART II: ENQUIRY AS LOGIC

For years textbook writers, teachers, and science educators acted as if there was a scientific method. "The Scientific Method" was the common phrase. No one, of course, holds this view any longer. Instead we talk of the methods of science, and of the patterns of enquiry of science. We also talk of the method or pattern of enquiry described by philosopher X and the method or pattern of enquiry described by philosopher Y. I have elsewhere argued that we should begin to explore the curricular possibilities of a wide range of these philosophical conceptions of scientific method.[3]

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[1] Presented at the conference of the Science Teaching Association of Ontario, Toronto, Ontario, 14 November, 1969.

[2] This paper is based on a workshop sponsored by the Curriculum Department, The Ontario Institute for Studies in Education in the summer of 1968 on the development of enquiry materials in science.

[3] F. Michael Connelly, "Choices in the Selection of Theories of Enquiry for Purposes of Curriculum Construction" (Paper presented to the Canadian Association of Professors of Education, Toronto, 1969).

However, for purposes of this afternoon's meeting, we shall circumvent this exploration by describing very general characteristics of scientific enquiry. These characteristics apply to much research in many areas of science. Notwithstanding this attempt at generality these characteristics do not apply to all science at all times. Let us list and describe these characteristics.

Conceptions Governing Enquiry

Enquiry begins and is governed by conceptions of how the subject-matter may profitably be analysed for enquiry. These conceptions are ordinarily not recognized by the enquirer. Rather, they exist as unstated principles of enquiry. These principles dictate how the enquirer should divide his subject-matter into parts and they further tell him what kind of questions to ask of the subject-matter. An example of such a guiding conception is the notion of structure-function in biology. Enquiry governed by the conception of structure-function begins by analysing the subject-matter - e.g. ecological community, organism, bodily system, cell-into components parts. Thus, for example, an ecological community may be divided into producers, consumers and decomposers and a cell may be divided into the nucleus, cytoplasm, mitochondria and vacuoles. The research then seeks to describe the functions of each of the parts. The following account of the structure-function principle and its role in William Harvey's classical investigation of the circulatory system is illustrative.

In his Biology Teachers Handbook Schwab gives an account of the structure-function principle as follows.

> In this conception the "whole" has its place. It is a "going" concern with a certain character or nature. That character or nature is expressed through a number of capacities and activities characteristic of it. Thus the character or nature we call "animal" is expressed through a catalogue of capacities and activities as familiar as it is venerable, that is, ingestion, digestion, distribution and assimilation, excretion, locomotion, integration, reproduction, and so on.

> . . . These capacities and activities, in turn, make certain demands. There are conditions that must be held within bounds and needs that must be supplied if they are to maintained. It is here that the "parts" play their role. They are servants of the whole, supplying its needs as well as constituting its visible existence. . . . Organs, in turn, may be treated as wholes while we investigate, as their parts, the tissues, the variety of cells, even the microstructures, which compose and maintain them . . . . The leading question we are asked in each such investigation is clear enough. What is the role of each part in the whole economy? It is at this point that the conception makes it crucial commitment, sets forth the notion which is at once its greatest strength and its sorest point. That notion is briefly and simply this: The structure of every part, the location of every part, and its observable actions of or in every part are all appropriate to, neatly fitting for, the role it plays in the whole.[1]

Schwab lists seven kinds of evidence for function which are clearly derived from the character of the principle. The seven are:

1. The overall shape and appearance of an organ or part
2. The observable change or motion of that part
3. The relation of that part to other parts
4. The shape and appearance of that organ's components
5. The observable change or motion of the components
6. The relation of the components to one another
7. The behavior of the organism[2]

Let us turn to an outline of the heart enquiry beginning with the problems and proceeding through the data required, the methods used in obtaining the data, and the statements of knowledge gained. Following this outline we will make a point by point comparison of our example with Schwab's account of the structure-function principle. We will proceed by closely following the justly famous enquiry by William Harvey entitled An Anatomical Disquisition on the Motion of the Heart and Blood in Animals.[3] The subject-matter of this enquiry is a part of the organism, the heart, discriminated by anatomical criteria from other parts with which it is associated. The overall problem of the enquiry is to determine the function of the

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1 Joseph J. Schwab, "Invitations to Enquiry," in Biology Teachers Handbook (New York: John Wiley and Sons, Inc., 1964), pp. 188-90.

2 Ibid., p. 179.

3 William Harvey, An Anatomical Disquisition on the Motion of the Heart and Blood in Animals, trans. by Robert Willis (London: J. M. Dent and Co., 1908).

heart. This requires the evidences listed above and, accordingly, the immediate problems are (1) to determine the location and connections of the heart relative to other organs; (2) to describe the morphology of the heart; (3) to determine the morphology, relationship, and action of components of the heart: (4) to discover the action of the heart relative to other organs; and (5) to determine the action of the heart relative to the functioning of the organism.

Clearly, one set of required data are descriptions of heart location within the organism and relative to other organs. These data are obtained by dissection and observation of the organism and its parts. Another set of required data consists of a description of chambers, valves and even muscle fibers described according to their physical relationship to one another. Still a third set of required data consists of observations of the motions of the heart relative to the motions of associated organs. Thus, for example, the contraction of the left ventricle is seen to correspond to a subsequent pulse in the conus arteriosus. Functional data of this sort are obtained by observing the action of the heart under as normal circumstances as is possible. Finally, the data are interpreted to give an outcome of the form, "The function of the heart appears to be to circulate blood. . .The function of circulation for the organism is. . . ."

Let us compare this illustration with schwab's account of the structure-function principle. In the following, Notes 1-6 are quotations from Schwab[1] and Comments 1-8 relate the notes to the illustration.

Note 1

> In this conception the "whole" has its place. It is a going concern with a certain character or nature.

Comment 1. -- Our illustration describes a particular enquiry and does not specify the context from which the enquiry derives its significance. Had it done so,

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[1] Above, pp. 2-3.

we would have begun with statements identifying the class of organisms involved. These organisms might have been animals in general or a particular class of animal.

Note 2

That character or nature is expressed through a number of capacities and activities characteristic of it.

Comment 2.-- Again, we have not specified the capacities, although we allude to them in our final statement of knowledge gained, i.e., "The function of circulation for the organism is. . . ." One of the capacities alluded to by this statement is that the organism is an "air breather"; another is that the organism is active throughout warm and cold seasons and is what is called "warm blooded."

Note 3

These capacities and activities, in turn, make certain demands. There are conditions that must be held within bounds and needs that must be supplied if they are to be maintained. It is here that the "parts" play their role. They are servants of the whole, supplying its needs as well as constituting its visible existence. . . .

Comment 3.-- The capacities "air breather" and "warm blooded" are "held within bounds" by the respiratory and circulatory systems. These parts are interrelated but for purposes of enquiry we treat them separately and turn our attention to the circulatory ststem.

Note 3

Organs, in turn, may be treated as wholes while we investigate, as their parts, the tissues, the variety of cells, even the microstructures, which compose and maintain them.

Comment 4. -- Our illustration takes two steps in the direction of reducing wholes to parts and these again to parts. We focus on the heart, a part of the circulatory system, treating it as an analogical whole. Consequently, Notes 1-3 are now taken to refer to the heart. Thus, the first two problems relating to location and morphology illustrate Note 1 by aiming at knowledge of the character of the heart. Note 2 is illustrated by the fourth problem on the action of the heart, and Note 3 by the third problem on the composition of the heart.

Note 5

The leading question we are to ask in each such investigation is clear enough. What is the role of each part in the whole economy? It is at this point that the conception makes its crucial commitment. . . . The notion is briefly and simply this: The structure of every part, the location of every part, and the observable action of or in every part are all appropriate, neatly fitting for, the role it plays in the whole.

Comment 5. -- There are two levels of concern here. First, the structure and arrangement of muscles, valves and chambers are treated as being so organized that the actions of each are related to the character of the heart, namely its contractions. Second, when we return the heart to its role of part, this character, now treated as the action of the part with respect to the whole, is evidence for the function of the heart. Furthermore, the relationship between the heart and conus arteriosus is such that the action of each is related thereby allowing the heart to perform its function.

Note 6 (Evidence for function.)

1. The overall shape and appearance of an organ or part
2. The observable change or motion of that part
3. The relation of that part to other parts
4. The shape and appearance of the organ's components
5. The observable change or motion of the components
6. The relation of the components to one another
7. The behavior of the organism

Comment 6. -- (1) Solution to problem 2. (2) Solution to problem 4. (3) Solution to problem 1. (4) Solution to problem 3. (5) Solution to problem 3. (6) Solution to problem 3. (7) Our enquiry has not recorded organism behavior. We would need to observe that the organism did or did not hibernate; was relatively indifferent, or responsive to, climatic change; or whether the organism was capable of rapid change in activity. From these data we would infer variations in action of the heart under different environmental circumstances.

Comment 7.-- The evidence in this enquiry can, of course, only be obtained by observation and dissection. Experimental methods such as removal of parts or all of the heart are clearly inappropriate. However, the principle does not rule out in vivo experimental techniques provided their interference with the normal functioning of the heart is slight. Thus, an enquirer interested in the relationship between the heart and the nervous system might stimulate the large nerve (vagus nerve) associated with the heart and observe subsequent heart action.

Comment 8.-- The products of enquiry obtained according to the structure-function principle carry a certain burden of uncertainty. As Schwab points out, there is no guarantee that an enquirer has judged correctly with respect to the efficient action.[1] In our case, for example, heart relaxations, rather than contractions, might have been mistakenly selected for taking account of the function of the heart.

A physiological examination of the heart could, of course, be guided by a quite different principle. An enquiry, for instance, guided by a conception of the homeostatic control of blood gases might treat the action of the heart as a mechanism which moves blood through various organs. The problem of the enquiry is, now, to determine how the action of the heart helps to maintain relatively constant gas levels in the blood. Data would be required on the additions and substractions of blood gases by these organs and on the variations in heart action in response to variations in blood gas level. The data would be interpreted to give an outcome of the form, "The heart forces blood through organ 'X' where carbon dioxide is transferred to the blood and oxygen is transferred to the organ. . . When organ 'X' removes excessive amounts of oxygen from the blood, as in violent exercise, the heart increases its rate of action."

Fact

Facts are commonly treated as if they were fixed bits of evidence given to enquiry by the subject-matter. Thus, it is common to say "What are the facts?" as if this was the sole basis for judgement about an idea or theory. This notion of fact,

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[1] Joseph J. Schwab, personal communication, 1967.

however, is inconsistant with what takes place in enquiry. As we have seen the conception governing enquiry dictates how the subject-matter is to be analyzed. Accordingly, these conceptions dictate what will and will not pass for a fact in enquiry. For example, an enquiry using the structure-function conception will look for parts which are factually described in terms or size, shape, composition and relationship to other parts. The kinds of structure-function data are more fully described in Note 6 of the structure-function illustration.[1]

Facts are best seen as selected representatives. Given enquiries using given conceptions select a sample of data upon which the enquiry is based. Gregor Mendel, for example, in his well known studies of inheritance was exclusively concerned with traits sh ,ing discreet inheritance - e.g., tall-short, green-colorless, wrinkled-round. Mendel deliberately rejected all traits showing other forms of inheritance - e.g. size, a trait showing continuous variation.[2]

Mendel's work is especially interesting since it points up still another aspect with respect to data, namely, that data are often experimentally <u>constructed</u>, some would say "created", by the enquiry. The data on which Mendel's 3:1 ratios - e.g. 3 round peas: 1 wrinkled pea- are based are not found naturally. Plants growing in the wild do not exhibit 3:1 ratios. The ratios appear as artifacts of a highly controlled experimental situation. It is also of interest to note that in <u>no</u> case do the data give 3:1 ratio's. The famous ratio's are abstractions from actual ratios which are only close to the abstraction, e.g. from 3.06: 0.94.

Problem

A problem arises in enquiry when certain aspects or data of given situations are explainable and others are not. The determination of which data fit and are

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1 Above, p. 6.

2 Gregor Mendel, "Experiments in Plant Hybridization," in James A. Peters, editor Classic Papers in Genetics (Englewood Cliffs, N.J., Prentice-Hall, Inc., 1959).

explainable and which data do not fit and are not explainable depends on the state of knowledge with respect to the problem and on the particular conception governing the enquiry. The first of these - the state of knowledge - simply reflects the fact that enquiry is an ongoing process. The products of any given enquiry becomes a starting point for still other enquiries. For example, Mendel begins his paper by pointing out that ornamental plants exhibit regularities in their inheritance and that some characteristics disappear in one generation and appear in the next. For conceptions governing enquiry we notice that different conceptions provide different terms for problem formulation. Returning to our circulatory system example one way of stating a problem on heart motion is to ask "What structures are associated with the motion of the heart?" Still another way of stating the problem is to ask, "What are the inputs, translocations and outputs of the heart?" This is well illustrated in the enquiry of the circulatory system where, at the end of the illustration, the conception of homeostasis is compared with the conception of structure-function.[1]

Hypotheses

Hypotheses are best thought of as being tentative explanatory ideas. These ideas grow out of known facts (some which fit and some which do not) appropriate to a given problem and are used to explain the lack of factual fit and to make predictions about other possible facts. Situations, often experimental, are devised to gather these possible facts. Taken together both sets of facts-the facts with which the enquiry begins and the possible facts - act as the bases for modification and verification of the hypotheses.

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[1] Above, p. 7.

Interpretation

The movement from given facts (some which fit and some which do not) to hypotheses from hypotheses to given facts and new facts generated by the hypotheses and back again to a revised hypothesis may be thought of as a process of interpretation. Facts and hypotheses are not directly connected in the sense that one inevitably gives rise to the other. The process is analagous, in some respects, to light filtration in which the analogue of interpretation is a light filter. Thus, white light passed through a red filter comes out red and through a blue filter comes out blue. Furthermore, both binary orange light (orange composed of red and yellow) and binary green light (green composed of yellow and blue) passed through a yellow filter comes out yellow. Returning to interpretation and in analogy with the two filtration cases we say that the same facts can give rise to different explanatory ideas depending on the interpretation and that different facts can give rise to the same explanatory idea depending on the interpretation. The "filter" in this interpretation process is the conception or principle governing the enquiry. The direction moved in making an interpetation is guided by the conception. For instance, two biologists looking at the same data on heart motion will explain the motion in different ways if one thinks in terms of structure-function and the other thinks in terms of homeostasis.

Outcome

The outcomes of enquiry, whether limited statements of knowledge, concepts or full-blown theories, arise from the processes described above. Outcomes amount to the best explanations available at any point in time. They are not, as commonly treated in science textbooks, fixed and final products of enquiry.

As we have seen, outcomes are developed in terms of certain conceptions and depend on certain kinds of selected and constructed facts. Often in a discipline there are competing statements of theory and definition of concept. These differences arise, of course, because of the different governing conceptions and different possible facts which may be chosen for enquiry. Learning theory in psychology is a case in point and, in biology, the competing claims of different plant ecologists is illustrative.[1] Wendell Palmer has an excellent example in his paper on honey bee communication.[2]

To summarize, we have described six very general characteristics of enquiry-conception governing enquiry, fact, problem, hypothesis, interpretation, outcome. These characteristics of enquiry give rise to five very general and very important characteristics of statements of knowledge.

1. The meaning of a statement of knowledge depends on the logic-the pattern of enquiry-that gave rise to the statement. In this sense textbooks tend not only to reduce the complexity of meaning but, in stressing one or another single meaning and definition, tell lies.
2. Knowledge as found in journals and books is not true or right but, rather, the best, i.e. the most adequate, account of the world at any given time.
3. Knowledge statements change in the ongoing process of enquiry. Enquiry does not terminate in the sense suggested by textbooks.

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1 F. Michael Connelly, "Conceptual Structures in Ecology with Special Reference to an Enquiry Curriculum in Ecology" (unpublished Doctoral Dissertation, Department of Education, University of Chicago, 1968) Concepts such as "dominance", "succession" and "tolerance" are given different meanings and, are thereby used differently by ecologists using different ecological principles of enquiry. Furthermore in three of the five ecological problem areas four principles are used giving rise to a number of overlapping and competing outcome (knowledge) claims.

2 Wendel K. Palmer, "A Student Investigation of Classical and Recent Research Papers on Honey Bee Communication Designed to Illustrate, Through Discussion, Patterns of Scientific Enquiry" (Prepared for the OISE Workshop on Enquiry Materials in Science, Summer, 1969).

4. Knowledge is neither solely discovered nor solely invented. As we have seen there is a sense in which enquiry imposes ideas on subject matter and a sense in which ideas grow out of the subject-matter. Some people prefer to call this process "construction."
5. Logical processes of enquiry have intellectual and material components. The processes are not, as most proponents of laboratory instruction would have it, a mere matter of manipulating and working with things in a laboratory. The stress in our enquiry materials workshop is on the intellectual. One of the important goals of this workshop is to reaffirm and give methodological meaning to intellectual processes. This does not, of course, deny or suggest that laboratory instruction should be overlooked in the curriculum. In fact, a curriculum should reflect a proper mix of both.

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ENQUIRY MATERIALS IN SCIENCE TEACHING [1,2]

This is the third paper in a three part series on enquiry materials in science teaching. Part I, Conceptions of Enquiry, pointed out that different people use the word "enquiry" in different ways and that this leads to unnecessary confusion. In order to preserve the richness of meaning in the many uses of "enquiry" a classification of three sets of meanings was presented - enquiry as teaching method, enquiry as mode of learning, enquiry as logical disciplinary process.

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Part III, Enquiry into Enquiry, describes a discussion method for a teaching-learning situation aimed at an understanding of enquiry as logic. The teacher has in mind a set of conditions or structure which a profitable discussion will fulfill and by which it will be guided. These conditions are derived, in part, from enquiry as logic. Students are required to search for evidence

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to support positions taken, to compare and contrast the various arguments i.e. the movement from data to positions taken via a process of interpretation, and to engage in the reformulation of arguments. In brief, the class acts as an enquiry community.

Part III further describes various kinds of materials which can serve as the material basis for an enquiry into enquiry discussion.

PART III: ENQUIRY INTO ENQUIRY

We now turn to the methodological set of meanings of enquiry. The method, enquiry into enquiry, is suggested as a classroom approach to the teaching of enquiry in the logical sense.

Enquiry into enquiry is a discussion process. The process involves teacher-pupil interaction, pupil-pupil interaction and pupil-written materials action and stresses a search for evidence to support positions taken. The discussion group plays the role of research community. Questions are asked and answers are given. The questions put in discussion reflect the logical characteristics of enquiry. For science the major questions which can be put are questions on (1) problem, (2) data and (3) interpretation.

Schwab lists the following questions appropriate to the reading of materials representing a single line of thought:

What is the problem under investigation?

From what preceding discoveries and difficulties does it arise?

How well do the data represent the phenomena for which they stand?

What outstanding assumptions are involved in their interpretation?

To what conclusion?

What more is seen when this conclusion is joined to the conclusions of other papers?[1]

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[1] Joseph J. Schwab, "The Teaching of Science as Enquiry," Joseph J Schwab and Paul F. Brandwein, The Teaching of Science (Cambridge, Mass.: Harvard University

This set of questions assumes discussion materials with a single guiding conception and, further, that the teacher chooses not to put questions which explicitly show how the guiding conception governs the pattern of enquiry. If, however, the teacher chooses to deal explicity with guiding conceptions then the following additional questions and requests are required:

What are the important terms of the problem?

What do each of these terms do for the enquiry? (Some terms will identify the subject of enquiry e.g. heart cells, Florida hot springs. Other terms will indicate what is puzzling e.g. maintenance of the Ca:P ratio in sulfer hot springs. Still other terms will indicate how the subject-matter is to be analysed for enquiry e.g. composition, ratio, interaction.)

Show how these terms determine what data are required?

Show how these terms determine the procedures for collecting the data.

What are the important terms of the statement of outcomes (conclusion)? (As with the problem there are different kinds of terms playing different roles.)

Show how the movement from collected data to the statement of outcomes reflects the role of these terms.

Compare the terms of the problem, the terms of the statement of outcomes and the movement from data to outcomes.

Show how the patterns of enquiry from problem to outcomes is guided by these terms.

State the guiding conception.

The best enquiry into enquiry discussions use materials with more than one guiding conception. These are the "debate" and "disagree" materials: materials where the ideas, theories and facts of one research are challenged by another research. For example, in Palmer's materials von Frish's explanation of the dance of the honey bees, so familiar to biologists, is seriously challenged.[1] Discussions using materials with different guiding principles require the following additional comparative questions:

What specific question was one researcher able to ask that the other was not? Show how these are related to the terms of the guiding conception.

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1 Palmer, "A Student Investigation of Classical and Recent Research Papers on Honey Bee Communication" (Prepared for the OISE Workshop on Enquiry Materials in Science, Summer, 1969).

Which set of terms gave the most reliable data?

Which set of data gave the most reliable outcomes?

Which set of terms gave the most reliable account of the subject-matter under investigation?

What is a next possible problem emerging from each line of work?

Show that the outcomes and techniques of the second line of work could be recast in terms of the first line of work.

Student answers are not allowed to remain as mere matters of opinion but are referred to the written text for supporting evidence. The questions, as in enquiry more generally, do not have given answers. Rather, the answers depend on the particular evidence selected from the text. For instance, possible sources of evidence for the question, "What is the problem of the paper?" are the title of the paper, crude statements of the problem in various parts of the paper and the literature review which consitutes the knowledge out of which the problem arose. The following three quotations are taken from a paper in ecology[1] and illustrate these sources of evidence.

Quote I

Production Problems in Flowing Water

In recent years rapid advances in techniques and thinking have lead to conceptual schemes based on much evidence as to the workings of aquatic communities in lakes, estuaries, and oceans. By measuring the flux of energy, the energy partition, the controlling factors, and associated resulting biological phenomena, overall and characteristic quantitative patterns have been discovered. In contrast few attempts have been made to study overall community metabolism, to measure production rates, or to develop community concepts for streams.

The study of Silver Springs reported here has been made with the purpose of determining the basic structure and workings of flowing water ecosystems by the careful study of one stream under some unusually favorable conditions provided. In recent years such holistic consideration of the energy flux and biomass have provided a fruitful approach to the understanding of many types of ecological communities.[2]

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1 Howard T. Odum, "Trophic Structure and Productivity of Silver Springs, Florida," Ecological Monographs, XXVII (1957), 55-112.

2 Ibid., p. 58.

Quote 2

> The purpose of this research was to study the basic workings of stream ecosystems and factors controlling individual, population, and community productivity by an analysis of the unique conditions supplied by outflow from the largest and best known of these chemostatic springs, Silver Springs. . . .
> The general plan was to characterize the chemostatic flow, to establish the qualitative and quantitative community structure, to measure the production rates, and to study the mechanisms by which the community metabolism is self-regulated.[1]

Quote 3

> . . . a review and summary of the scattered but extensive literature on productivity of flowing waters communities have been presented elsewhere . . . but some principle hypothesis as to the workings of streams may be restated here before data are presented from Silver Springs (A list of eight hypotheses on productivity and efficiency is presented.).[2]

In the course of classroom discussion different answers to the question on the problem of the paper are advanced depending on the evidence chosen. One student, using the title as his evidence, may see the problem as an effort to account for Silver Springs in terms of energy levels and productivity. Another student, using the first quotation as his evidence, may see the problem in terms of its role in the testing and development of energy concepts for flowing streams. A third student, using the first part of the second quotation as his evidence, might agree with the second student or, using the second part of the second quotation as his evidence, may see the problem as an attempt to describe the chemical homeostasis . Silver Springs and the role of homeostasis in community metabolism. Still a fourth student, using the title and the third statement as his evidence, may see the problem as an attempt to determine the productivity and efficiency of Silver Springs in terms of its trophic levels.

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1 Ibid., p. 56.

2 Ibid., p. 59.

The following is a hypothetical clip from an enquiry into enquiry session based on Mendel's paper on plant hybridization.[1]

> The teacher challenges the class to "show the sense in which Mendel invents facts to develop and support his explanation of the inheritance of traits." One student responds by saying that the teacher has not chosen his words carefully and that the teacher meant to say "discovers facts". The teacher reaffirms the original wording of the question and the student temporarily retires from the discussion. A second student advances the unsummarized data of the first series of experiments as evidence that Mendel discovered the facts which were there for his taking all along and that Mendel brilliantly recognized the working of the binomial theorem in producing a summarized 3:1 ratio. The teacher agrees with the second part of the statement. A third student challenges the second and argues that Mendel's careful selection (3 years of selective breeding) and mating of his plants gave rise to the data. He further argues that, in the wild uncultivated state, these conditions do not prevail and that 3:1 ratios do not naturally exist. The first student, who has been giving silent but visible assertion to the second student's position suddenly says, "But this means Mendel faked his work. He created those ratios" The clip ends.

At the level of logical aspects of enquiry the clip has demonstrated, in part, the role played by the process of enquiry in selecting and organizing facts. Facts for this enquiry, are not seen as grudgingly given by a somewhat unremitting world but as telling bits of evidence invented in the process of enquiry.

At the level of enquiry into enquiry several things are in evidence. First, the class operates as a small research community, each of its members advancing ideas and challenging the ideas of others. Further, this process is not opinionated but depends for its success upon supporting evidence drawn from the materials under discussion. The teacher is seen as a special member of this community: one whose job it is to initiate and maintain an enquiry. Initially, the teacher has in mind a model of enquiry which he uses to subtly structure the discussion so that it may properly be an enquiry into

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1 Gregor Mendel, "Experiments in Plant Hybridization," in James A. Peters, editor Classic Papers in Genetics (Englewood Cliffs, N.J., Prentice-Hall, Inc., 1959), adapted for classroom use by F. Michael Connelly.

enquiry. The teacher does not assume authority with respect to the positions advanced. Rather, the authority of the teacher is assumed with respect to the <u>way</u> arguments are advanced, compared and reformulated.[1] The first student is a particularly interesting one in this clip since his first comment illustrates the difficulty one has in moving from an accepted frame of reference to a new frame of reference. He reenters the conversation only after mulling over the discussion of others of the community and after coming to grips with the evidence and argument of the third student.

<u>Enquiry Materials</u>

There are almost no available materials to illustrate enquiry into enquiry. One of my projects is to develop video tape sessions for this purpose. There are, however, materials in various stages of development which are useful for teaching the logical aspects of enquiry. The following materials were used in our workshop.

Orginal papers- A set of papers in ecology was used illustrating the role of problems and principles in giving rise to a variety of patterns of ecological enquiry.[2] In addition Gregor Mendel's orginal paper on Plant Hybridization was used.[3] Other materials are becoming available from teachers such as John Eix,[4]

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1 I am indebted to my colleague Doug Roberts for my discussion with him on this concept of teacher authority.

2 These were developed by me on the bases of work reported

3 Mendel, "Experiments in Plant Hybridization" I have developed this paper for classroom use by inserting a series of "Notes" throughout the paper. Some of the "notes" explain difficult points and others ask enquiry questions. The student can work through the paper as an independent exercise and the paper may then be used for a class discussion.

4. John F. Eix, "Rutherford's Experiment" (A paper for discussion with teachers-in-training).

Wendel Palmer,[1] Harold Bricks, and John Harvey.[2]

Invitations to Enquiry- The "invitations" in Schwabs' Biology Teacher's Handbook[3] were used. These are designed to reflect the principles of biological enquiry.

Narrative of Enquiry- Geraldine Connelly's The Role of Paleontology in Developing Theories of Hominid Evolution[4] was used. This stresses the adequacy of a variety of theories of hominid evolution based on the patterns of enquiry appropriate to each theory.

Science Fiction Literature- A bibliography and classification of science fiction literature[5] was used. The classification allows us to identify substantive topics, aspects of enquiry and issues dealing with relationships between science and society in S.F. literature.

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1 Wendel K. Palmer, "A Student Investigation of Classical and Recent Research Papers on Honey Bee Communication."

2 Harold Bricks and John L. Harvey, "The Double Helix: The Molecule of Heredity" (Prepared for the OISE Workshop on Enquiry Materials in Science, Summer, 1969).

3 Joseph J. Schwab, Supervisor, "Invitations to Enquiry" Biology Teachers Handbook (New York: John Wiley and Sons, Inc., 1964), 43-226.

4 Geraldine A.M. Connelly, "The Role of Paleontology in Developing Theories of Hominid Evolution: A Teaching Unit" (unpublished Master's thesis, Department of Education, University of Chicago, 1967).

5 These materials are being developed by me at The Ontario Institute for Studies in Education.

Enquiry Games in Science- A game being developed by Allen et al was used.[1] The game stresses very general aspects of enquiry such as the role of hypothesis and is not tied to any particular subject-matter. Oscar Chappell has written a modified version of this game and is conducting local workshops on the use of the game.[2]

Case Histories- Leo Klopfer's History of Science Cases[3] were used. These stress the historical change and development of scientific theories.

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1 R. Allen, L. Klopfer and L. Liss, "QUEST: A Game for Questioning, Understanding and Expanding Scientific Thinking" (Nova Academic Games Project).

2 Oscar Chappell, "Academic Games Project: I.M.E." (Prepared for the OISE Workshop on Enquiry Materials in Science, Summer, 1969).

3 Leopold E. Klopfer, "History of Science Cases, Grades 9-12" (Toronto, Science Research Associates, Ltd.).

ANNOUNCEMENT

The workshop on enquiry materials in science will again be conducted in the summer of 1970. The workshop is non-credit but may, with consent of the instructor, be taken for credit by M.Ed. students. The workshop is sponsored by the Department of Curriculum of The Ontario Institute For Studies in Education. Interested people should write to F. Michael Connelly, or John Clipsham, The Ontario Institute for Studies in Education, Department of Curriculum, 102 Bloor Street West, Toronto 5, Ontario.